Assessment of Opportunities for Advanced Technology Repowering

Donald L. Bonk (dbonk@metc.doe.gov; (304) 285-4889)
Mark D. Freier (mfreie@metc.doe.gov; (304) 285-4759)
U.S. Department of Energy
Federal Energy Technology Center
3610 Collins Ferry Road
Morgantown, WV 26507-0880

Thomas L. Buchanan (tom_s_buchanan@parsons.com; 610-855-2677)
Michael R. DeLallo (mike_r_delallo@parsons.com; 610-855-2675)
Harvey N. Goldstein (harvey_n_goldstein@parsons.com; 610-855-3281)
Jay S. White (jay_s_white@parsons.com; 610-855-2693)
Parsons Power Group Inc.
2675 Morgantown Road
Reading, PA 19607

Introduction

The opportunities for applying advanced technologies developed under the U.S. Department of Energy's (DOE) clean coal demonstration program are expanding in both domestic and international markets. Potential retirements and the competitive pricing dominating the domestic energy markets are placing demands on power generators to improve efficiency and reduce operating costs. Internationally, significant growth in economic development requires innovative and reliable technologies to support the use of indigenous coal. These markets provide new opportunities to establish the strategic benefits of Clean Coal Technologies (CCT) and increased market potential where coal is a viable option.

Objectives

The objectives of the study were to compare thermal and economic performance of a suite of advanced clean coal technologies in a repowering application under a consistent set of guidelines, including compliance with Clean Air act requirements.

Approach

This study evaluated the technical and design challenges involved in repowering conventional pulverized coal power plants, and estimated the capital costs and operating costs for various clean coal technology options. The approach taken in this study was to define a reference pulverized coal (PC) fired power station, and then apply each candidate technology in succession. Each case was modeled in a modified version of the ASPEN flow sheet simulation program, along with a suitable combustion turbine, where applicable, and the host plant steam cycle.

Pittsburgh No. 8 coal is used for most of the cases evaluated, except for one case involving a natural gas fired combustion turbine, another case where the technology variable is the use of a Process Derived Fuel (ENCOAL Corp. PDF) in place of coal, and a third case where coal is the primary fuel, but some natural gas is used for topping combustion.

The reference station configuration was based on an evaluation of a UDI data base containing the complete domestic U.S. generating fleet. Based on this evaluation, a Reference PC host plant was defined, consisting of twin 150 MWe nominal size PC units, with steam conditions of 1800 psig/1000F/1000F. Each unit utilizes a steam turbine with a triple flow LP turbine section, with 23 inch diameter last stage buckets exhausting to a single pressure condenser at 1.0 in. Hga. Heat rate, when new, was 9150 Btu/kWh, HHV.

In this study, the original steam turbines are refurbished and reused, along with much of the steam cycle equipment. This is an important consideration, as it constrains the configuration of the power conversion cycle, whereas in a greenfield plant the designer can select optimal steam cycle design parameters and equipment. However, certain advantages accrue from this approach, such as the ability to retain the original once-through cooling system, which provides low condensing pressure and auxiliary power requirements. Refurbishment of the original turbine includes replacement of selected steam path components, which improves adiabatic efficiency by about 1-1/2% relative to its performance as delivered.

As each advanced technology was evaluated, a combustion turbine was selected for the topping cycle portion of the power conversion system. Based on a time frame for application in the years 2000 to 2010, the Westinghouse 501G machine was selected for use where feasible. This large, efficient combustion turbine provides sufficient exhaust heat for the bottoming cycle to match effectively with most of the cases evaluated, while only requiring a single machine to be installed. In the cases involving the first and 1-1/2 generation Circulating Pressurized Fluid Bed Combustors, (CPFBC) the W501D5 machine was used, as it provided a more suitable match for the overall system. The bubbling bed Pressurized Fluid Bed case relies on the ASEA GT-140P machine.

Description of Technologies

1. Reference Pulverized Coal Plant. See Reference Plant Definition, above. Net output for both refurbished units, combined, is 294 MWe at a heat rate of 9009 Btu/kWh, HHV.

2. Atmospheric Fluid Bed Combustor. This case is based on a typical design available for commercial service at this time. Existing coal handling equipment and other infrastructure are refurbished and reused. Plant performance is relatively unchanged except for emissions, which are significantly reduced. Solid waste production is increased.

3. Refueling with Process Derived Fuel (ENCOAL Corp.). This case is a refueling rather than a repowering. The original boilers are refurbished, along with the steam turbines and other site equipment, and fired with 100% ENCOAL Corp. PDF, a dried and mildly pyrolised Powder River Basin coal. The fuel is specified to contain low sulfur as delivered, (0.3% sulfur, by weight). Original boiler capacity is maintained, with enhancement of soot blowing capacity, and other modifications to compensate for the somewhat different combustion characteristics of the process derived fuel. This refueling results in a slight reduction in net output to 293 MWe, and a slight reduction in net heat rate to 8890 Btu/kWh, HHV.

4. Pressurized Fluid Bed Combustor (Bubbling Bed). This technology is represented by the Asea Brown Boveri (ABB) P-800 commercial module, using an Asea Stahl GT-140P gas turbine. In this study, the combustor is located inside a pressure vessel that is 57 feet in diameter and 160 feet high, operating at a nominal pressure of 245 psig. Net plant output is increased to 350 MWe, while net plant heat rate is reduced to 8679 Btu/kWh, HHV.

5. Pressurized Fluid Bed Combustor (Circulating Bed, First Generation), based on Foster Wheeler technology. This concept utilizes a circulating pressurized fluid bed for combustion of the coal, with hot gas leaving the bed at 1600F and cleaned in a series of cyclone and ceramic candle filters. The gas is ducted to a gas turbine for expansion. A machine based on the W501D5 is used in this arrangement, with a single drum Heat Recovery Steam Generator (HRSG) in the exhaust to supplement the steam production in the Fluid Bed heat exchanger. Plant net output is increased to 314 MWe, while net heat rate is reduced to 8506 Btu/kWh, HHV.

6. Pressurized Fluid Bed Combustor (Circulating Bed, One and One-Half Generation). This version of CPFBC technology is similar to the first generation scheme mentioned above. In this case, natural gas is fired in the combustion turbine to reach the original design turbine inlet temperature of the machine. An external, motor-driven boost compressor is used to compensate for the unrecovered pressure drop in the CPFBC circuit external to the gas turbine. The W501D5 is again selected, exhausting through economizer coils for condensate and feedwater heating. Steam is produced in the Fluid Bed Heat Exchanger to drive both of the existing steam turbines. Plant net output is increased to 368 MWe, while net heat rate is reduced to 8087 Btu/kWh, HHV.

7. Pressurized Fluid Bed Combustor (Circulating Bed, Second Generation). In this case, a pyrolizer is added to the process. Low Btu fuel gas produced by the pyrolizer is conveyed to the gas turbine where it is mixed with the returning vitiated air from the CPFBC and combusted to produce the design basis firing temperature of the turbine. This configuration is based on the use of a modified W501G machine, with an external, motor-driven boost compressor as in the previous case. Steam is produced in a HRSG and in the Fluid Bed heat exchanger to drive both of the steam turbines in the existing station. Net output is increased to 434 MWe, while net heat rate is reduced to 7040 Btu/kWh, HHV.

8. Integrated Gasification Combined Cycle (IGCC) (Air Blown KRW Gasifier). This case utilizes the air blown, fluidized bed, KRW gasifier, with hot gas cleanup and a transport type gas polisher to supplement the gasifier bed sulfur removal. The clean hot low Btu gas is fired in a modified W501G gas turbine, coupled to a HRSG for steam production. Both existing steam turbines are repowered in this example, providing a net station power increase to 406 MWe, and a reduction in net heat rate to 7374 Btu/kWh, HHV.

9. Integrated Gasification Combined Cycle (Oxygen Blown Entrained Bed Gasifier). In this example, a two-stage, entrained flow gasifier is supplied with 95% pure oxygen from an on site air separation plant. A single gasifier module produces medium Btu fuel gas which is desulfurized in a GE moving bed cleanup system and then fired in a modified W501G machine. The turbine exhausts through a HRSG to produce steam to drive one of the two existing steam turbines. A Monsanto type (H_2S burning, catalytic conversion) sulfur recovery process produces commercial grade sulfuric acid for sale as a byproduct. The net station output is increased to 353 MWe, while net heat rate is reduced to 7378 Btu/kWh, HHV, (including the air separation plant and other auxiliary loads).

10. Integrated Gasification Combined Cycle (British Gas/Lurgi Oxygen Blown Gasifier). This fixed bed gasifier is supplied with 95% pure oxygen from an on-site air separation unit. The gasifier produces a cold medium Btu gas, which is desulfurized in a Purisol cleanup train. Tail gas from the Purisol unit is converted to commercial grade sulfuric acid for sale, in a Monsanto type H_2S burning and catalytic conversion unit. The fuel gas is fired in a modified W501G machine, which exhausts through a HRSG to produce steam to drive one of the existing steam turbines. A portion of the compressor discharge air is supplied to the high pressure air separation plant. This repowering example produces a net power increase to 317 MWe, and a heat rate reduction to 7581 Btu/kWh, HHV.

11. Integrated Gasification Combined Cycle (Air Blown Transport Reactor). This IGCC concept is based on the air blown transport reactor. The hot low Btu gas is desulfurized in the reactor, followed by a polishing step in a transport desulfurizer, chloride removal in a chloride guard bed, and filtration in a ceramic candle filter array. The fuel gas is fired in a modified W501G machine and exhausted through a HRSG to produce steam for one of the existing steam turbines. This transport gasifier is based on concepts being evaluated at the DOE Power Systems Development Facility in Wilsonville, AL. This unit will not be commercially available at the beginning of the reference time frame, but can be ready for service by the year 2010. This case results in an increase in net output to 368 MWe, and a reduction in heat rate to 6853 Btu/kWh, HHV.

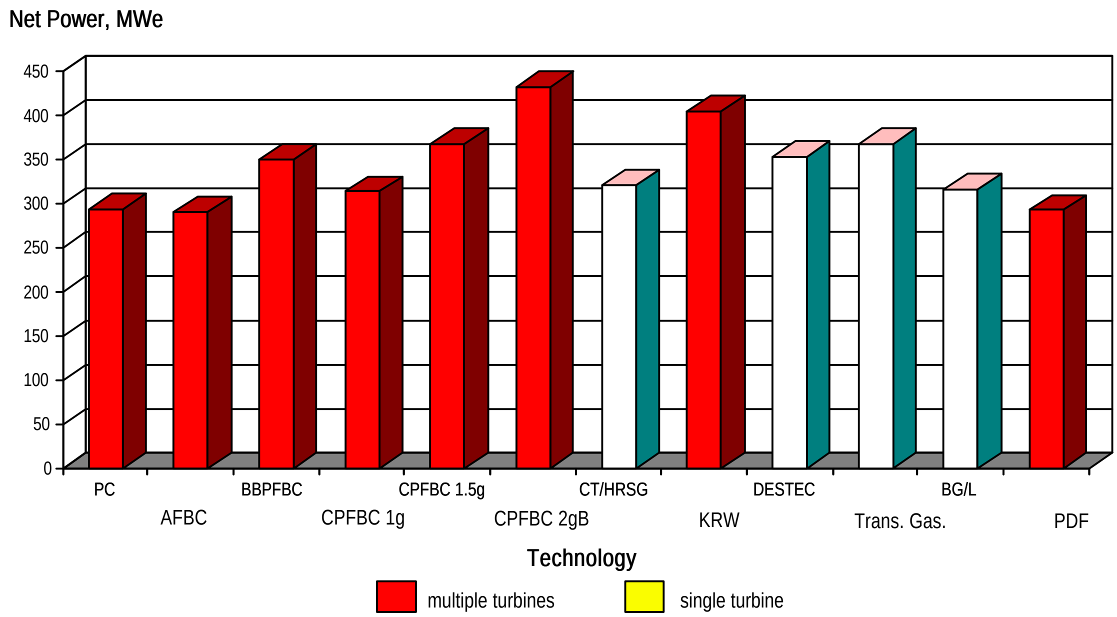
12. Combustion Turbine/Combined Cycle. A natural gas fired, state-of-the-art combustion turbine is used in conjunction with a HRSG to repower one of the two existing steam turbines in this case. The W501G machine is coupled to a multi-pressure HRSG to provide a net station output that is 321 MWe, with a net heat rate of 6881 Btu/kWh, HHV. Two gas turbines repowering both existing steam turbines were not used, since the resulting net power would be more than double the original output, and in excess of study guidelines. The second of the two original steam turbines is placed in reserve status.

Results

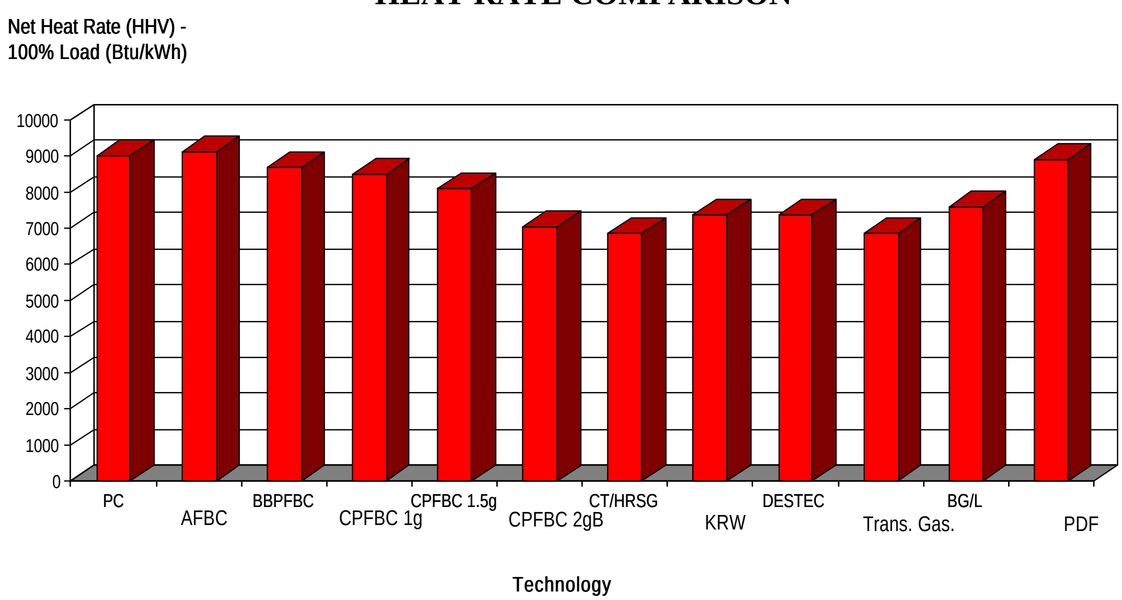
The completed study provides thermal performance for each repowering application, as well as conceptual capital costs and economic projections. The study results should be interpreted on a relative basis. Changes in site conditions, financial ground rules and inputs, or other factors can impact the thermal and economic performance of the technologies.

Based on the inputs adopted for this study, stated in the report, the following comparisons are presented: The first two graphs illustrate net electric output and heat rate (HHV) for the various repowering configurations. In several instances, only one of the two existing steam turbines is reused. For these cases, as noted on the graphs, utilization of the second steam turbine would have required additional combustion turbine capacity, and would have yielded about twice the net power output. This large increment of power was considered to be beyond the site transmission capacity, and therefore was not attempted.

TOTAL NET PLANT GENERATION

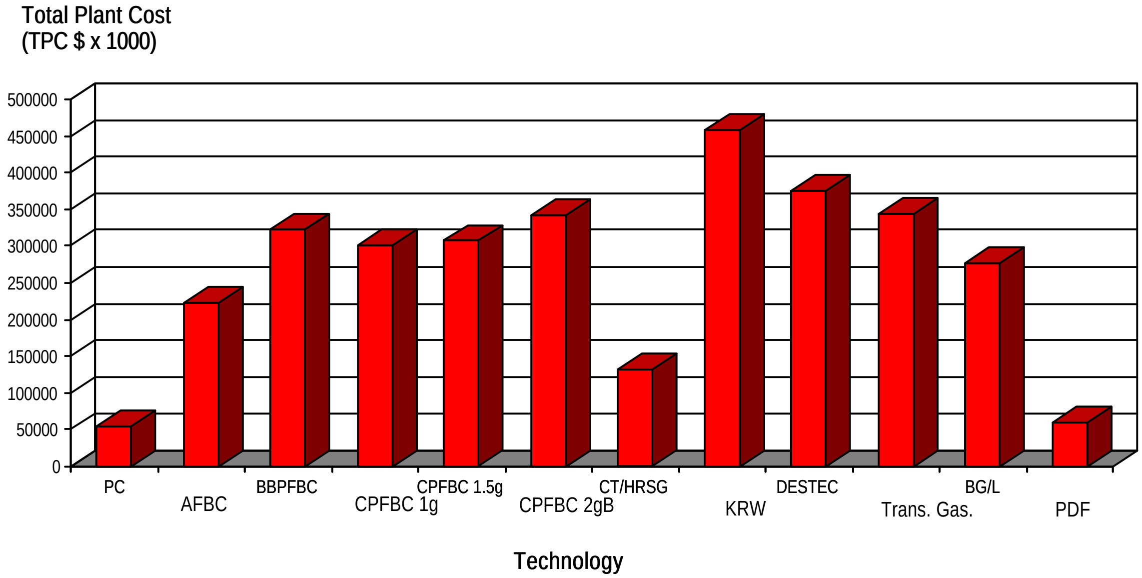


HEAT RATE COMPARISON

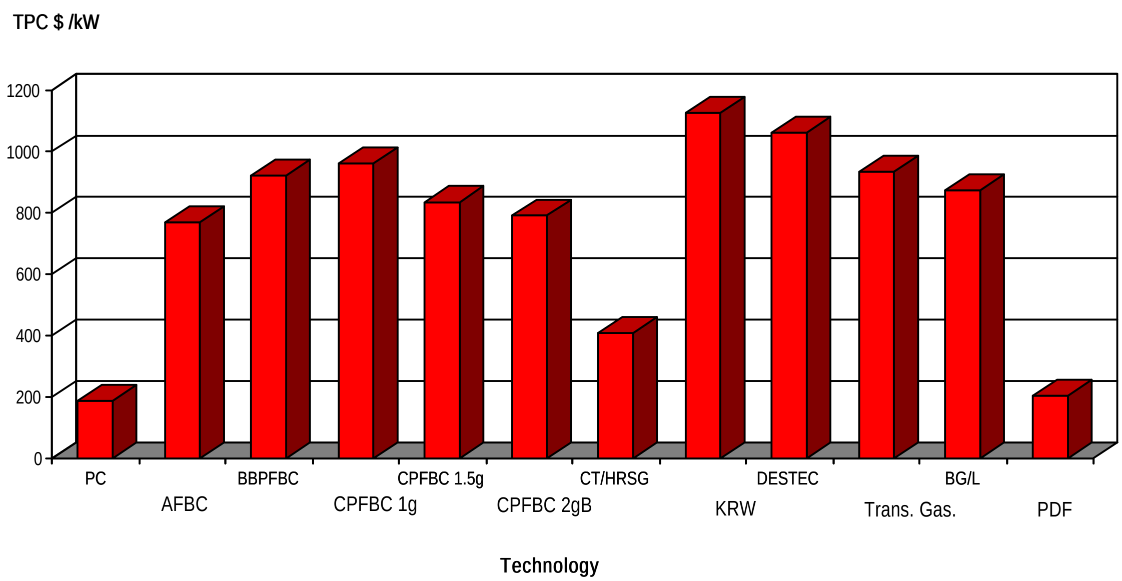


The second set of graphs presents plant capital costs on a Total Plant Cost (TPC) basis, both in absolute and in per kWe terms. As a group, the advanced technologies range from about $750 to $1100 per kWe, in this repowering application.

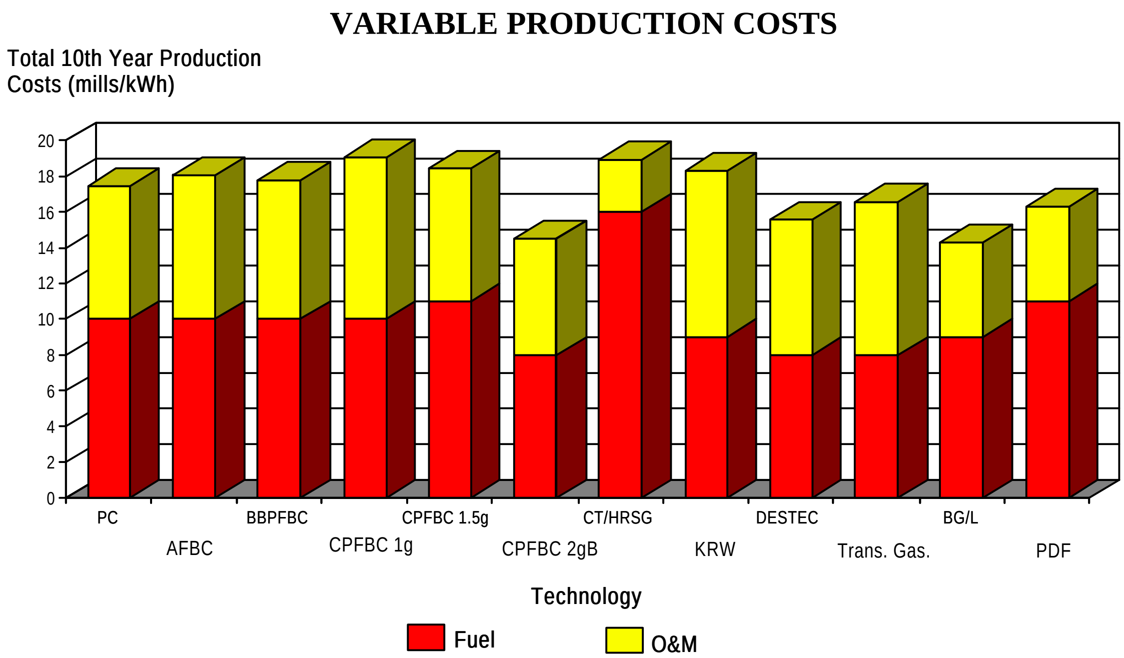
TOTAL PLANT COST

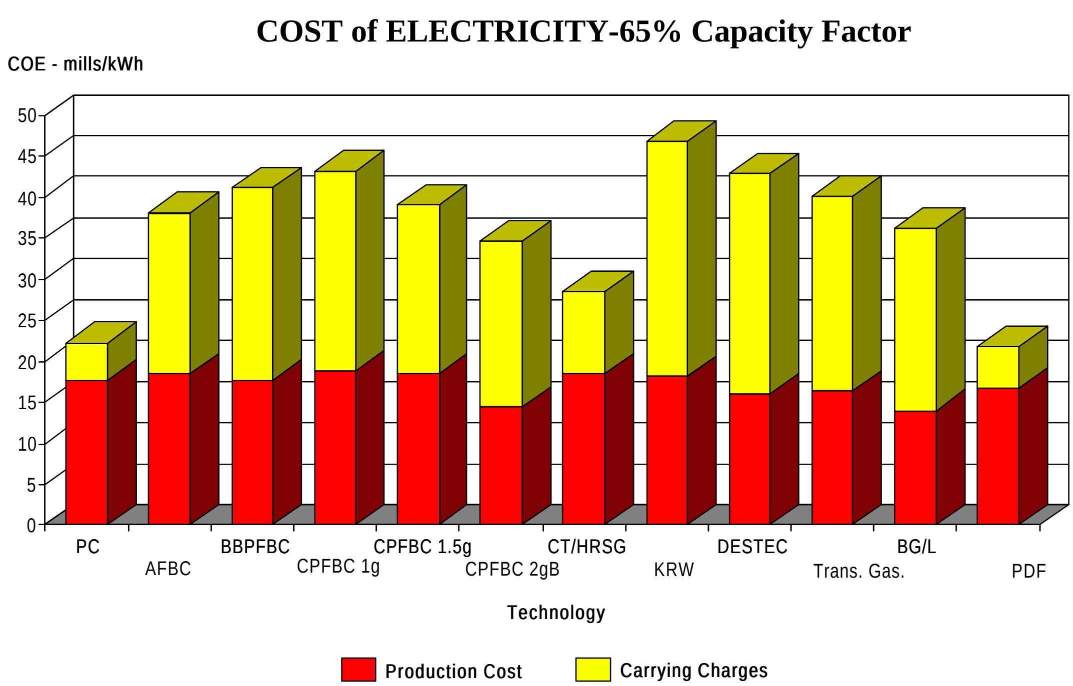


TOTAL PLANT COST/kW



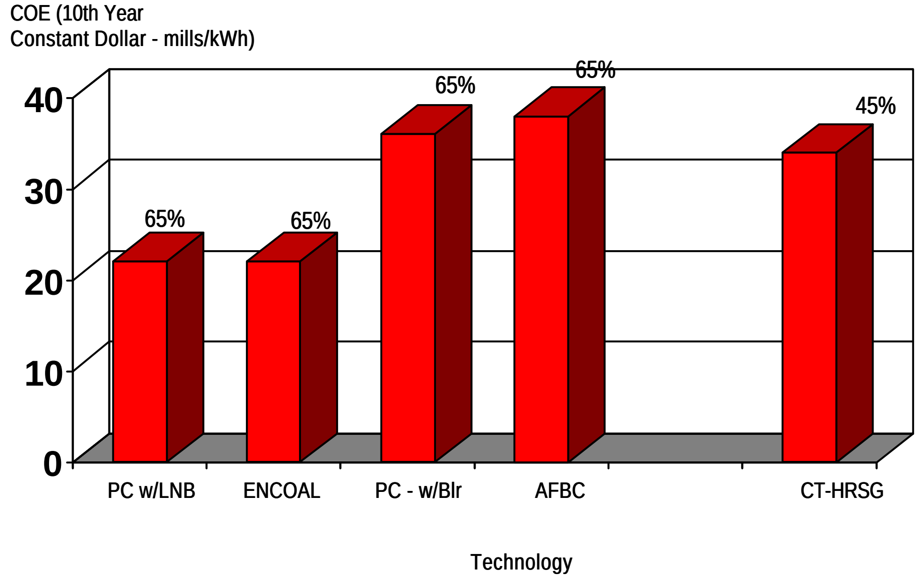
The next charts compare variable and fixed costs for the technologies evaluated. The first chart compares variable costs, which are comprised of the following components: fuel, sorbent, consumables, emissions credits or charges, byproduct credits or charges, and the variable portion of operation & maintenance. The second chart shows estimated values for the Cost of Electricity, with a constant capacity factor of 65%.



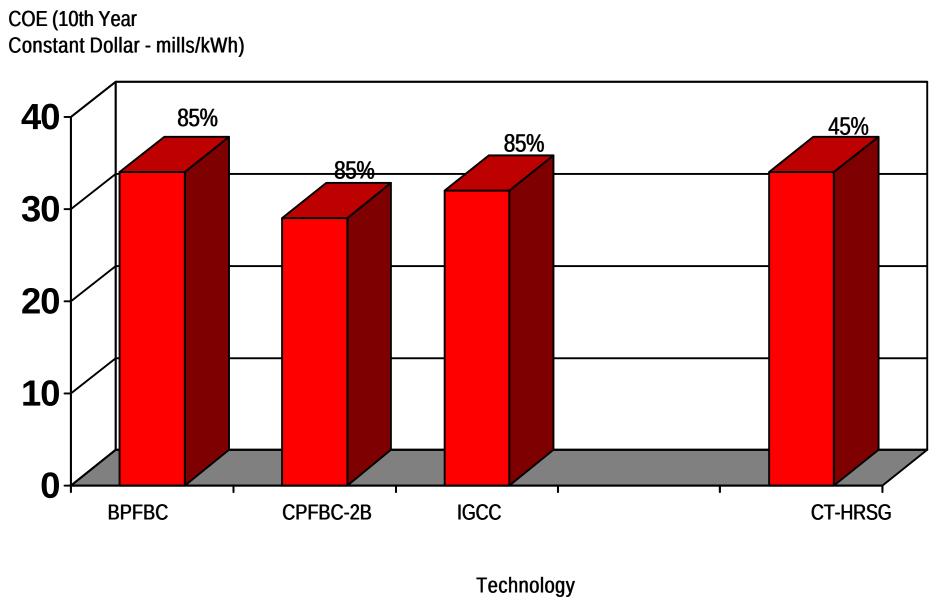


The next series of charts compares the current technologies and advanced technologies in separate groups. Capacity factors (CF) are varied, with current technologies evaluated at a 65% CF, the natural gas fired combustion turbine/HRSG at a 45% CF, and the advanced technology cases at an 85% CF. The IGCC graph bar is a composite of the Destec, Transport Reactor, and BG/L cases. The Reference Plant life extension and ENCOAL PDF refueling cases provide the lowest COE, but are limited by the remaining life of the boiler. If a boiler replacement is performed, the COE rises to the level of the AFBC case.

COE with VARIABLE CAPACITY FACTORS-Current Technologies

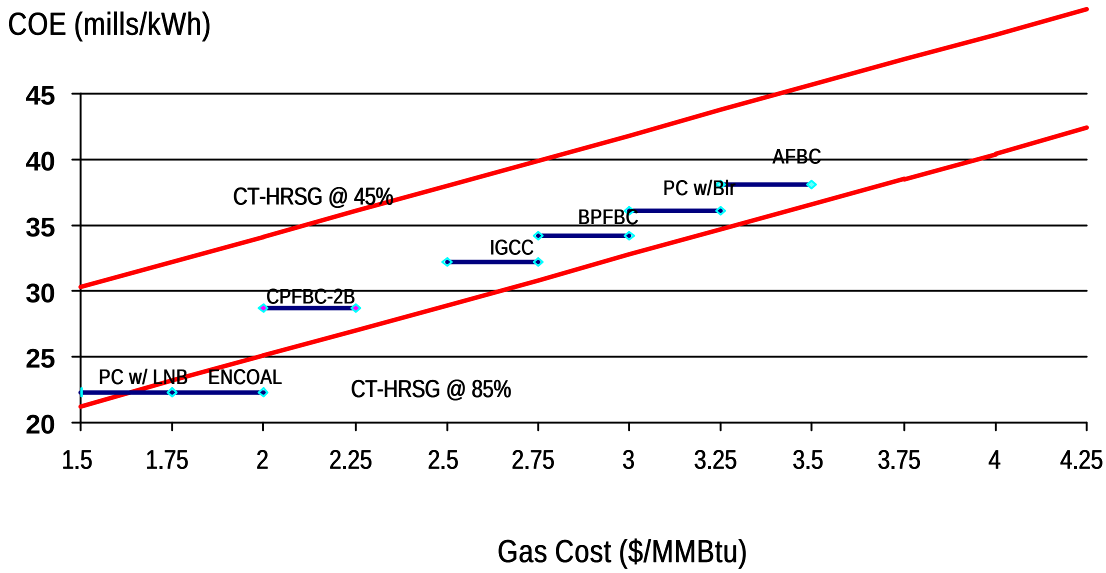


COE with VARIABLE CAPACITY FACTORS-Advanced Technologies



The final graph shows the range of repowerings against a backdrop portraying the CT/HRSG COE values as a function of gas price. Note that the advanced technologies become competitive when gas prices rise above about $ 2.10/MM Btu. Thus, a window of opportunity may open for the solid fuel fired advanced technologies as gas prices rise, provided that the promise of these technologies is convincingly demonstrated to suppliers and users of commercial risk capital.

NATURAL GAS CTCC VS. SOLID FUEL TECHNOLOGIES



Contract Information

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Acknowledgment Information

Work reported on herein was carried out as Task 1 of the above noted contract. Period of performance was from October 1994 to July, 1997. The METC COTR in the first several years of the study was Donald Bonk; John Rockey is the current COTR.